INVESTIGATIONS ON CONTINUOUS CONTROL VALVE FOR WATER HYDRAULICS

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ABSTRACT

Environmental protection regulations are becoming increasingly strict. Using water instead of hydraulic mineral oil in power-control hydraulic systems we can make a very positive step in complying with these regulations. In this paper we present a newly developed hydraulic test rig that is designed for these specific requirements of water as the hydraulic fluid in power control hydraulics. For direct comparison with the oil system, the test rig is designed as a twin system with two equivalent circuits: one operating with water and the other with mineral hydraulic oil as hydraulic fluid. The new water proportional 4/3 directional control valve (specimen) was constructed, developed, manufactured and tested in the scope of our laboratory. Some important results about dynamic responses of the water and the oil system are presented and compared. They show significant differences between the water and oil hydraulics. The paper also briefly shows the change of the leakage through time at the duration test. In the paper presented duration test was made up with 2.5 million cycles. The used hydraulic liquid was distilled water; working temperature was in the range from 30 to 35 °C, setting pressure of the pressure relief valve was up to 160 bar.

KEYWORDS: high pressure water systems, power-control hydraulics, distilled water, proportional directional control sliding type valve, stainless steel

1. INTRODUCTION

Unexpected outflows of hydraulic liquids, i.e., mineral oils, into the ground and even into the underground drinking water supplies are a frequent occurrence. One of todayôs major challenges to prevent harmful consequences for the environment is to use the alternative, from which the best are natural and biodegradable, sources of hydraulic fluid. In power-control hydraulics (PCH) there are two ways in which we can protect the environment. The first solution is to use the biodegradable oil [1] to [6] instead of mineral oil, and the second, in any case better solution, is to use tap water instead of mineral oil. This solution is totally harmless to the environment, but is very difficult to realize [7] to [9]. Namely only some relatively simple conventional control valves exist on the market today. In spite of many years of the research work on the field of water power-control hydraulics there is still insufficient understanding of the mechanisms and performances playing important functional role in application of PCH and consequently the available component designs are rare. Some of the reasons lie in many specifics in which water differs from mineral oil as hydraulic fluid in hydraulic systems. They play an important role already in the developing and research phase, and later in the long term ï useful life time tests. Par example, for any research work on the field of water hydraulics in real-scale components and parameters, home/laboratory made components and test rigs are required and should be made because they do not exist on the market. But this is tied up with relative high costs and technical problems. Much lower viscosity of water compared to that of mineral oil causes high leakage when using clearances typical for oil. On the other side the reduced clearances result in excessive wear and high friction and they are more difficult to achieve. Higher working temperatures, which are not allowed, but are often still common for mineral oil hydraulic systems, i.e. up to 70 or 80 °C, are hardly acceptable for water power-control hydraulic systems because of the evaporation at local contact spots [10]. Inside the water micro the organisms develop with time. They cause several and severe problems with chemical change of water and developing algae what results in sediments. Tribological properties of conventional materials (stainless steel) in water are unfavourable, but the comparable material selection is poor, and their properties are almost unknown for this usage. Corrosion and cavitation are other well known problems related to tribological performance and useful life-time of the components. Therefore, understanding and research of chemical and tribological properties that affect useful life and performances, as well as stationary and dynamic characteristics of water hydraulics, are required for successful development of new components. It is necessary for wider and accelerated use of water as hydraulic fluid in power control hydraulics.

The newly developed hydraulic test rig that is designed for specific requirements of water instead of mineral oil as hydraulic fluid is presented in this paper. For the direct comparison with oil system, the test rig is designed as a twin system with two equivalent circuits: one for water and the other for mineral oil as hydraulic fluid. Important results on dynamic responses of both systems are presented. Paper also shows the dynamics response of unloaded and loaded water proportional directional control valve, the bodeös plot.

All presented results show acceptable, not too high, differences between the water and the oil hydraulics. It appears and can be accepted as optimistic for further research and development on the field of water power-control hydraulics.

2. EXPERIMENTAL

2.1 TEST RIG

The double test rig, realized as twin test rig, one part of it intended to investigate water power-control hydraulics (PCH) and the other part to investigate comparatively oil PCH, was built and put to work [11 to 15]. This twin test rig has been used also to test and investigate the water and, comparatively, also the oil valve, both being proportional 4/3 directional spool-sliding control valves. The test rig has been used to carry out the comparative dynamic-transient and static long-term useful life-time tests under the equal, or at least, analogue working conditions. Figure 1 shows the hydraulic circuit of the water part of the test rig. It contains standard axial piston pump (pos. 1), with the flow 35 lpm [11 to 15] at 1450 r/min at the initial volumetric efficiency 97%. This pump delivers water through the pressure compensated flow control valve (pos. 2), which ensures constant flow of 33 lpm through the specimen ï the proportional directional control valve (pos. 3). This valve was controlled from the PC in closed loop. On the connection port A of the proportional valve we have had connected stainless steel tube to which further the pressure transmitter (pos. 4.1) and two ball-valves (pos. 6.1 and 6.2) are mounted on. Ball-valve pos. 6.1 was opened and ball-valve 6.2 closed when we measured dynamical response of the whole water system. Hydraulic cylinder (pos. 7) was used to find out the dynamic response of the circuit. Closed ball valve pos. 6.1 and opened ball valve pos. 6.2 were used to establish the response of the water proportional valve (pos. 3) and for the duration test. Fixed orifices, inside these pipelines, each of them with diameter of 1.5 mm (pos. 5.1 and 5.2), were used to simulate the load at the ports A and B of the specimen (water proportional valve). The second branch on the connection B on the proportional directional valve (pos. 3) was equal to the first just described. The water relief valve (pos. 8) was set to 160 bar. Centrifugal water pump (pos. 11) was used to maintain constant temperature through the cooler (pos. 12) and to enable an off-line filtering (pos. 13).

Pressures on the P and T connection ports of water proportional valve were measured during test using two pressure transmitters (pos. 9 and 10). Control of the proportional magnets, data acquisition and control of the electro-motors were provided and automated through a PC.

The oil part of the hydraulic test rig is equal/adequate to the water test rig, concerning function, but it is assembled using standard on-market-disposable components.

The liquid in the water PCH part of the test rig was distilled water to ensure a neutral environment that does not reflect the water type from any particular part of the world. The liquid in the oil PCH part of the test rig was the mineral oil according to ISO VG 46.

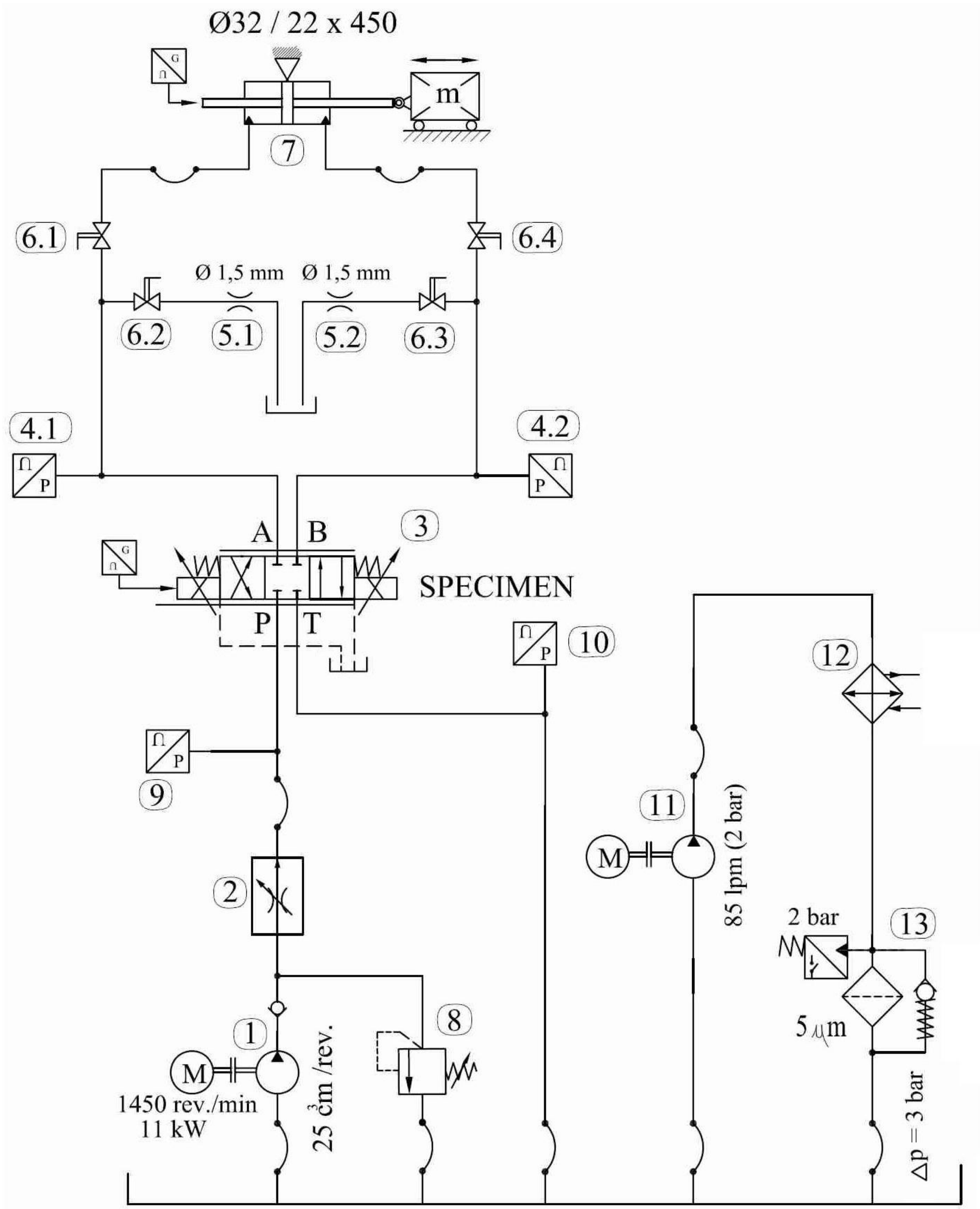


Figure 1. Hydraulic circuit of water test rig

Figure 2 shows photography of the double test rig. Oil part of test rig is on the right side and the water part on the left.

Figure 2. Double, water and oil hydraulic test rig

2.2 Proportional valve

A new, water proportional 4/3 directional control valve was developed in our Laboratory. The important parts used in this new water 4/3 proportional directional spool sliding control valve ï the specimen (Fig. 3) were the spool with an outer diameter of 12 mm and the sleeve. The static clearance between the spool and the sleeve was in the range of spool sliding valves of high quality. For this test the spool and the sleeve both were manufactured from stainless steel. This material combination, including some other material pairs, was previously verified and tested in tribological experiments [11 and 15]. For the stainless steel acceptable wear, but rather high coefficient of friction, was obtained in this research. According to these findings, dynamic testing in terms of repeatability due to dimensional stability appears acceptable, but some additional dynamic transient phenomena can occur as a consequence of too high friction and consequently stick-slip phenomena.

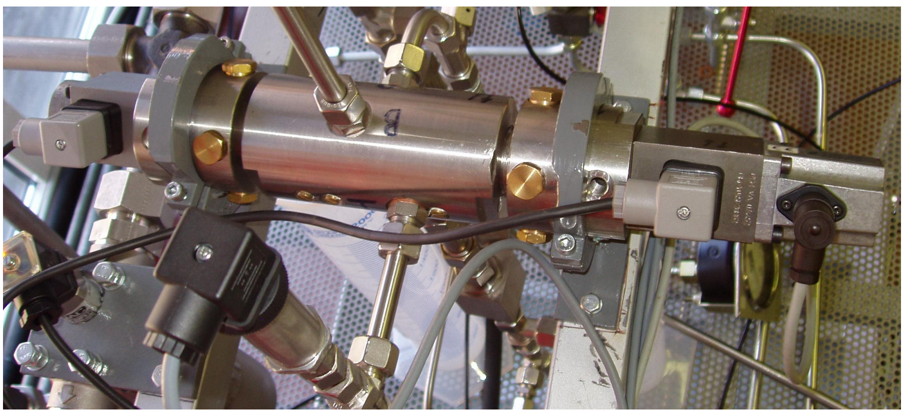


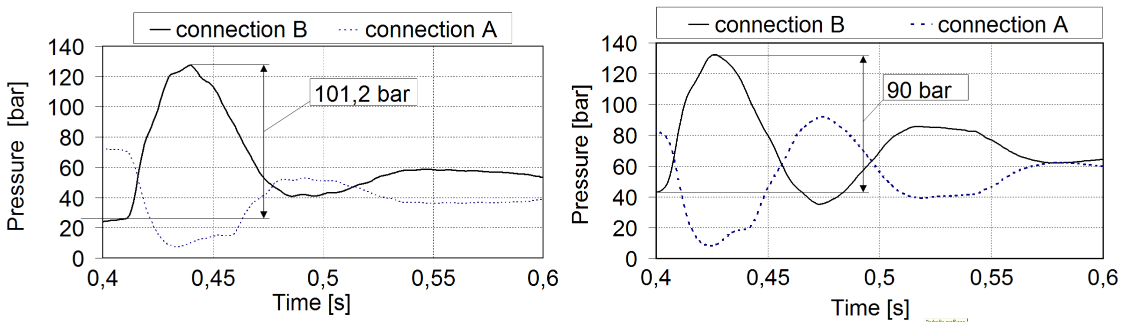
Figure 3. Specimen, water proportional 4/3 directional control valve

3 RESULTS

3.1 Dynamic responses of water and oil hydraulic system ï pressure surge effect

One of the most important dynamic characteristic of hydraulic systems is pressure surge effect. The difference of pressure surge effect was searched between the oil and the water hydraulic system at the same parameters. It is well known that compressibility of the hydraulic fluid has a great role in phenomena of pressure surge effect [16 and 17]. Furthermore water has higher compressibility than hydraulic mineral oil [7, 8 and 15].

Procedure of measurement, beginning at zero: proportional valve (Fig. 1, pos. 3) was, after 0.4 seconds de-energized from parallel position to neutral-zero position. Using the other words, the moving rod of the hydraulic cylinder, with coupled mass on it, was stopped and pressure surge effect occurred inside the pipeline on the connection port B of the proportional valve. Figures 4.a (water) and 4.b (oil) show the pressure surge effect proceeding from fast closing of the proportional valve at the flow 33 lpm, inlet pressure 160 bar and hydraulic cylinder loaded with roller-guided mass of 163 kg moving in horizontal direction. The pressure increase at instantly stopping of the fluid flow and consequently of the moving mass, in water hydraulic system was 101.2 bar and in oil hydraulic system, at the same parameters, only 90 bar. We can also clearly see high damped pressure vibrations in water hydraulic system in comparison with analogue oil hydraulic system.



a. *b.*

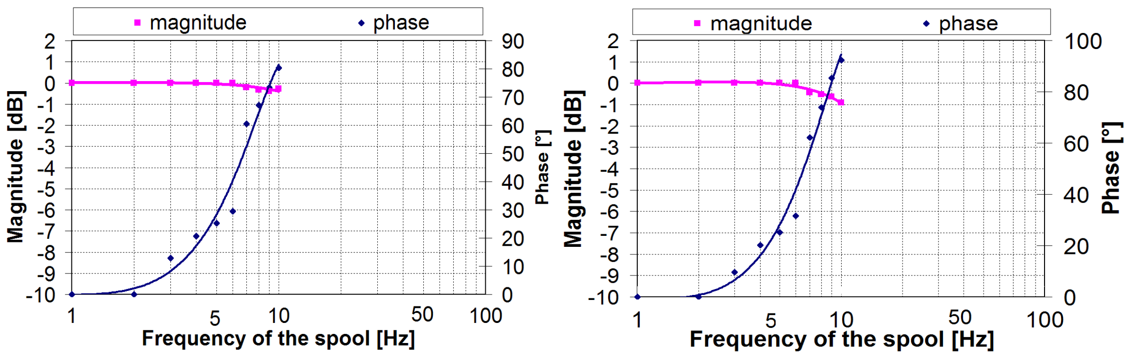
Figure 4. Pressure surge effect in a) water and b) in oil hydraulic system at inlet flow 33 lpm, inlet pressure 160 bar at P port of proportional valve and hydraulic cylinder in horizontal position loaded with mass 163 kg

3.2 Dynamic responses of the water proportional control valve

Dynamic responses to control signals are an identity card of each continuous control valve, such as proportional and servo valve. Different measurements at the frequencies 0.5, 1, 2, 3, 4, 5, 6, 7, 8, 9 and 10 Hz were done to determine the response of the water proportional control valve. The main observed parameters were input electric controlling signal and movement of the spool observing through time.

Figure 5.a and 5.b show the responses of the water proportional directional control valve on 100 % input sine-shape signal in Bodeôs plot. Figure 5.a shows Bodeôs plot for the unloaded water proportional directional control valve (without flow and pressure on

the valve) and fig. 5.b Bodeôs plot for the same water proportional valve at the inlet pressure 160 bar (on the port P, Fig. 1, pos. 3) and flow through valve approximately 20 lpm at working pressure 120 bar (on ports A and B, Fig. 1, pos. 3). It is evident that was response (magnitude) of the tested water valve in unloaded case (Fig. 5.a) for approx. 0.6 dB at 10 Hz better than response of the same valve with load (Fig. 5.b) at the same frequency. Phase delay was in the case of unloaded water valve at 10 Hz approx. 80° (Fig. 5.a) and in loaded valve for more than 10° longer (Fig. 5.b).



a. *b.*

Figure 5. Bodeôs plot for water proportional directional control valve for 100 % input signal for a) unloaded valve, b) loaded valve with the inlet pressure (port P) of 160 bar, working pressures (on ports A and B) of 120 bar and flow through valve aprox. 20 lpm.

3. 3 Duration test

Duration test of 2.5 millions of testing cycles with spool and sleeve from hardened stainless steel was carried out at the same testing conditions.
Frequency of the spool during lifetime test was 5 Hz and its control signal +/- 100 %. Pressure on the P connection was 160 bar, maximum pressures on A and B connections depended on flow through orifices (Fig. 1, pos. 5.1 and 5.2) and were approximately 120 bar. Working flow through orifices was approximately 20 lpm.
The measured internal leakage of water 4/3 proportional directional control valve was the main result of the useful lifetime test. Increasing value of leakage, when there was single ï by-pass filtering used, from start to approximately 2.5 millions of testing cycles is shown in Figure 6. Each point ï dot in diagram shows the mean value of at least three measurements of internal leakage at 40° and pressure 160 bar. There are three curves in the diagram. The first one (the main) represents the measured values for the water valve. It shows how the internal leakage increases from initial 0.036 lpm up to 0.0843 lpm at the same conditions. Possible reason for oscillating about the mean values of internal leakage during lifetime test lies in different positions (more or less central inside the bore of the bushing) of the spool in the time of leakage measuring process. The second line (the thin line) shows the predicted, calculated value for the internal leakage for the water proportional valve. It is extrapolated from the initial measured values taking into account normal working parameters. The third ï dashed line shows the predicted, calculated value for the internal leakage for the oil proportional directional control valve. This curve too is extrapolated from the initial measured values taking into account normal working parameters for such oil hydraulic systems working at 50 °C and 160 bar.

We did not carry out the lifetime test for the equivalent oil proportional valve, so we calculative predicted an average increasing of the gap between the spool and the bore of the sleeve of the oil sliding type of valve for 3 εm in 2.5 millions cycle period. After 2.5 million cycles the internal leakage of the water valve was lower as the predicted internal leakage of oil valve.

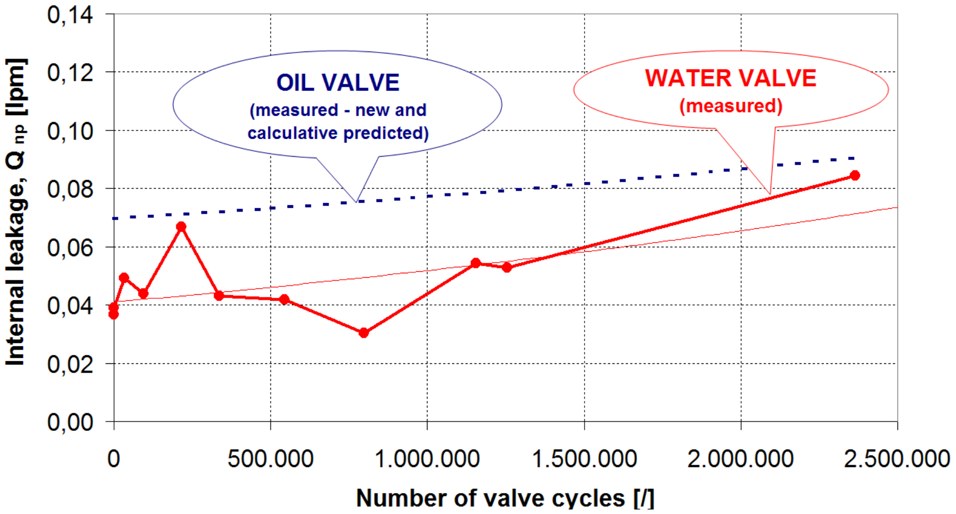


*Figure 6. Measured values of the internal leakage of water and oil directional 4/3 proportional control valve during the whole lifetime test, depending on number of switching cycles at single, by-pass filtering (by-pass filter was 5 **ε**m with $ß_{10}$>5000) (pressure = 160 bar, flow = approx. 20 l/min, frequency = 5 Hz, T_{water} = 40°C, T_{oil} =50°C)*

4 CONCLUSSION

- Analytical comparisons between dynamical responses of water and mineral oil hydraulic system show that differences are acceptable.
- Pressure surge effect in the water hydraulic system was for 12 % higher than in oil system; it is acceptable and according to the properties of both fluids.
- Response of the water proportional valve in unloaded state was at 10 Hz aprox. -0.3 dB and in loaded state -0.9 dB at 10 Hz. Response is acceptable for major simple hydraulic systems.
- Lifetime test of the new water proportional 4/3 directional control valve was carried out. Results are acceptable for application. The good filtering of water is very important.
- Results of lifetime test (2.5 millions of cycles) show that wear inside the water valve with stainless steel sliding elements is stabile and below the limit that is normally acceptable for the oil valve.

The results of presented research work show that we can be optimistic about usability of water power-control hydraulics in future. The overall results were better as being expected.

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